

# Current Status of the Shanghai VLBI Correlator

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**Abstract** Shanghai Astronomical Observatory has upgraded its DiFX cluster to 420 CPU cores and a 432-TB storage system at the end of 2014. An international network connection for the raw data transfer has also been established. The routine operations for IVS sessions including CRF, AOV, and APSG series began in early 2015. In addition to the IVS observations, the correlator is dedicated to astrophysical and astrometric programs with the Chinese VLBI Network and international joint VLBI observations. It also worked with the new-built Tianma 65-m radio telescope and successfully found fringes as high as at X/Ka and Q bands in late 2015. A more powerful platform is planned for the high data rate and massive data correlation tasks in the future.

**Keywords** VLBI correlator, IVS, astrometry, radio telescope

## 1 Introduction

The VLBI group at the Shanghai Astronomical Observatory (SHAO) has a long history in the development of VLBI correlators. The domestic software correlator and hardware correlator are mainly developed and applied for the VLBI tracking system in the Chinese deep space missions. The worldwide open source software correlator called DiFX was adopted at SHAO in 2012 and works as a dedicated correlator for astrophysics and geodesy. The computer cluster and the data storage

system of the DiFX correlator has been upgraded in the end of 2014. It has 420 CPU cores and a 432-TB storage capacity (Figure 1). An international high-speed network connection for raw data transfer among the main correlators and geodetic stations is established. As of the beginning of 2015, the DiFX correlator also serves as an IVS correlator. So far, more than ten IVS sessions such as CRF, AOV, APSG, and CRDS sessions as well as a few Australian geodetic VLBI sessions have been processed by the platform.



**Fig. 1** Hardware deployment of the Shanghai VLBI correlator.

Besides the IVS correlations, the platform also serves the astrophysical and astrometric programs conducted with the Chinese VLBI Network (CVN) and international joint VLBI observations. Meanwhile, the newly-built Tianma 65-m telescope will cover the frequency range from the L to the Q band together with two dual-frequency receivers in S/X and X/Ka. The DiFX correlator successfully worked with the Tianma 65-m and found fringes as high as at X/Ka and Q bands in late 2015.

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## 2 Performances and Operations

### 2.1 Platform Performances

The computer cluster shown in Figure 1 is divided into two groups for routine operations. Each head node manages ten computing nodes and 200 CPU cores in total. The main features including the hardware, the software, and the network conditions are as follows. The maximum correlation speed is around 1 Gbps per station when processing ten stations simultaneously (Figure 2). There are more than six staff members

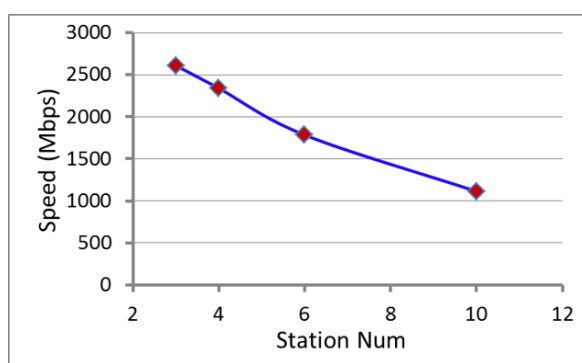


Fig. 2 Correlation speed of the Shanghai VLBI correlator.

(about 50% working time) for different parts of the operations from data delivery to giving out the final outputs.

- Correlator: DiFX-2.2/2.3/2.4/trunk  
Post-processing software: HOPS 3.9/3.10/3.11/3.12
- Head nodes: DELL R820 (E5-4610 CPU, 2.4 GHz, 2\*6 cores), 64 GB Memory; DELL R730 (E5-2623 CPU, 3.0 GHz, 2\*4 cores), 64 GB Memory
- Computing nodes: 20 DELL R630 nodes, 400 cores in total, two socket Intel E5-2660 CPU (2.6 GHz, ten cores), 64 GB Memory
- I/O nodes: RAID6, 432 TB raw storage capacity
- Mark 5 units: three Mark 5A and three Mark 5B.
- 56 Gb Infiniband for internal computing network connection
- 1/10 Gb Ethernet for internal & external network connection

### 2.2 e-transfer

In order to process global IVS sessions, the network links to Fortaleza, HartRAO, Hobart, Kashima, Noto, and Sejong stations as well as the Bonn correlator have been established (Figure 3). However, the links are not connected in a real time mode and some time slots of connections are negotiated before the data transfer. The two Shanghai VLBI stations are in a 10 Gb link to the VLBI center while other CVN stations are in a much lower rate connection. Most of the high data rate and long duration recording experiments are still through shipment of the diskpicks in CVN.

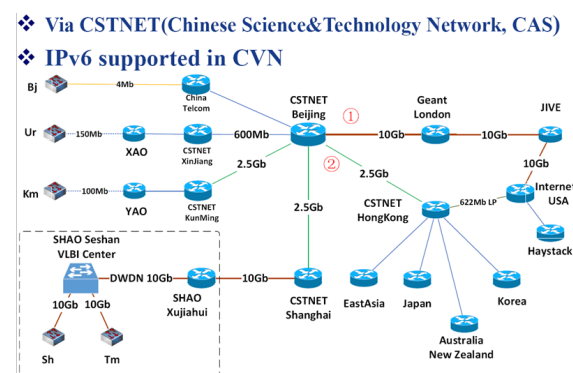


Fig. 3 Network conditions at Shanghai VLBI center.

### 2.3 Statistics of Correlation Operations

Some comparisons of the outputs after correlation and post-processing were made between the Shanghai DiFX correlator and the Bonn DiFX correlator in late 2014. The RMS of the group delay differences in the X band extracted from an S/X session were within a few picoseconds. In early 2016, a similar comparison was made between the two correlators. The results listed in Table 1 implied the group delay of the two correlator outputs coincided at the picosecond level.

Besides serving the global IVS sessions, the DiFX correlator is open to make correlations for the astrophysical and astrometric programs with CVN, east Asian, and Australian joint VLBI observations. Table 2 gives a summary of the correlations.

**Table 1** Comparison results of the Shanghai DiFX and Bonn DiFX correlators. Group delay and rate as WRMS of the differences.

Baseline	S band			X band		
	SNR ratio	Group delay (ps)	Rate (ps/s)	SNR ratio	Group delay (ps)	Rate (ps/s)
Ny-Ts	1	2.4	0.0127	0.992	1.1	0.0085
Ny-Wn	1	5.6	0.0208	1.002	1.6	0.0095
Ny-Wz	1	3.8	0.0156	0.994	0.9	0.0041
Ts-Wn	1	4.6	0.0198	1	1.7	0.0091
Ts-Wz	1	2.8	0.0113	0.994	0.9	0.0063

**Table 2** Summary of correlations processed. [In CVN-(CN): Js (Jiamusi), Ks (Kashi), and two deep space stations of China.]

Session Code	Observation Type	Times in a year	Stations participated	Recording rate
AUS-(AST,GEO)	Geodesy	12 (2016)	Australian, more than 4 st.	1024 Mbps
CVN-(CN)	Geodesy	4	CVN, Js and Ks, more than 3 st.	512 Mbps
CVN-(PSR)	Pulsar Astrometry	not fixed	CVN, 3 or 4 st.	1024 Mbps
CVN/EAVN	Astrophysics	not fixed	CVN or EAVN, more than 4 st.	1024 Mbps
IVS-(AOV, APSG, CRDS, CRF, RD)	Geodesy	>10	Global, up to more than 10 st.	256/1024 Mbps
VEPS	Astrometry	6	east Asian and Australian, 3 or 4 st.	2048 Mbps

### 3 Some Results

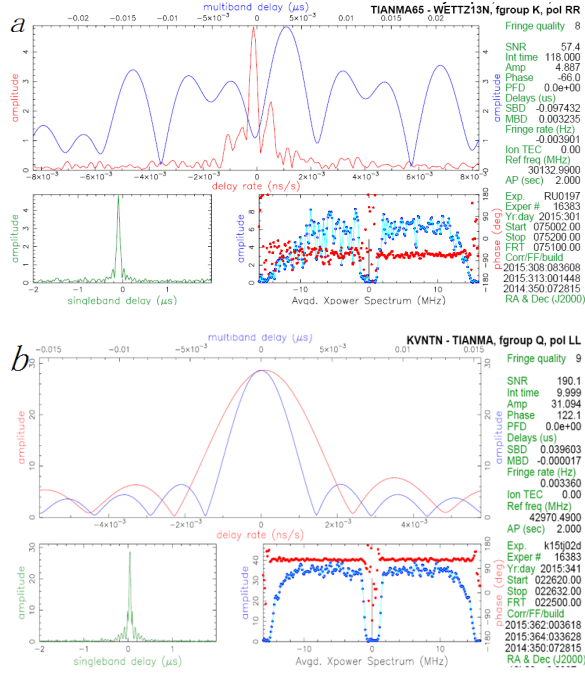
#### 3.1 IVS and Astrometric Programs

Thus far, there were 15 IVS sessions (including eight CRF, three AOV, two APSG, one AUG, and one CRDS sessions) processed and databases given out to the Analysis Center by the Shanghai correlator. The main time consumption was in the raw data delivery. Three CVN stations including Kunming 40-m, Shanghai 25-m, and Urumqi 26-m participate in regular IVS sessions. The accuracy of their station positions achieves a few centimeters due to these long-term global geodetic sessions. It helps to carry out some astrometric programs based on the three stations. As also presented in these proceedings, an ecliptic plane survey program was based on the above three stations together with one more session with Hobart, Kashima, and Sejong. The capability of the DiFX correlator made it possible to have different quantifications and baseband bandwidth among different stations. In the first phase of observations, there were 435 target sources detected in three or more observations among more than 2000 candidates in the source pool. The detection rate was near 20%. A pulsar astrometry program has conducted with the S-band receivers at the three stations. Five epoch phase-referenced VLBI positionings of the millisecond pulsar B1937+21 were carried out from 2012 to 2015. The signal-to-noise ratio of the pulsar signal was improved by pulsar gating during the correlations. After EOP, station positions, and ionospheric delay correc-

tions, the best fitted proper motion in RA and DEC were  $0.1237 \pm 0.18$  mas/yr and  $-0.2585 \pm 0.52$  mas/yr with a problematic parallax  $\Pi = -0.678$  mas. Regardless of the parallax, the proper motion parameters were consistent with the 15.5 year timing solutions of  $0.087(16)$  mas/yr in RA and  $-0.41(3)$  mas/yr in DEC. A deeper analysis is needed for the error mitigation.

#### 3.2 Tianma 65-m Related

The new-built Tianma 65-m radio telescope is about 6.1 km away from the Shanghai 25-m telescope. The receivers that were installed provide a continuous frequency coverage from L-band to Q-band. Two dual-frequency receivers in S/X and X/Ka bands play an important role in the geodetic activities. Besides of single dish observations, Tianma 65-m is also an important site for the VLBI community. Some joint observations with the KaVA, the EVN, and the VLBA have already been carried out in the low frequency bands. Fringes at high frequency bands including X/Ka and Q were found in late 2015 (Figure 4-a, 4-b). The X/Ka experiment was carried out with Tianma-Wettz13n-Zelen13m in RU0197 session. While the Q-band experiment was a Tianma-KaVA joint observation, an ad-hoc room temperature receiver was used in the experiment and the cooled dual-beam receiver is under installation in 2016.



**Fig. 4** a. Ka (X/Ka) band fringes to Tianma 65-m. b. Q-band fringes to Tianma 65-m.

## 4 Conclusions

The DiFX platform at SHAO is dedicated to the astrophysical and the geodetic VLBI observations. It has served as an IVS correlator since 2015. The platform is also open to the CVN and the joint international VLBI observations. Concerning the next generation

broadband and dual polarization VLBI observations, the Shanghai correlator will continue to make its contributions to the data correlation and processing. For the future high data rate and massive data correlations, current network conditions will be one of the bottlenecks and must be improved. A more powerful platform with a high performance computing cluster and a competent storage system is also needed.

## Acknowledgements

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## References

1. Deller A T, et al. *PASP*, 2011, 123(901): 275.
2. <http://www.haystack.mit.edu/tech/vlbi/hops.html>.
3. Reardon, D J, et al. *MNRAS*, 2016, 455(2):1751.
4. Shu, F C, et al. *IVS 2014 Annual Report*, 2014.